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(54) **LOCALIZATION, MAPPING AND HAPTIC FEEDBACK FOR INSPECTION OF A CONFINED SPACE IN MACHINERY**

LOKALISIERUNG, ABBILDUNG UND HAPTISCHE RÜCKMELDUNG ZUR INSPEKTION EINES BEGRENZTEN RAUMES IN MASCHINEN

LOCALISATION, MAPPAGE ET DE RETOUR HAPTIQUE POUR L'INSPECTION D'UN ESPACE CONFINÉ DANS UNE MACHINE

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Description

TECHNICAL FIELD

[0001] The present invention generally relates to an apparatus and system including haptic feedback for inspection of machinery and more particularly, but not exclusively to a system with haptic feedback for inspection and mapping of an air gap region of an electrical machine.

BACKGROUND

[0002] Devices known as crawlers or miniature robot devices can be used to perform some tasks such as air gap inspection and wedge tapping without removal of the rotor in some types of electrical machines. In some applications disassembling the machine prior to inspection is difficult or unpractical from a cost or system complexity standpoint. Some existing inspection systems have various shortcomings relative to certain applications. Accordingly, there remains a need for further contributions in this area of technology.

[0003] Document EP 1 772 949 A1 discloses an ultrasonic miniature air gap inspection crawler.

[0004] Document US4889000 A discloses an electric generator inspection system that inspects a stator of an electric generator and that comprises an inspection apparatus mounted on a carriage that travels along the slots defined by the stator and an indexer that is mounted to the rotor of the generator and travels around the circumference of the rotor to deliver the carriage to the desired slot.

SUMMARY

[0005] The embodiment of the present invention includes apparatus and system with haptic feedback and mapping capabilities for inspection of a rotating electrical machine. Other not claimed examples include apparatuses, systems, devices, hardware, methods, and combinations of systems with haptic feedback for inspection of the rotating electrical machine with unique methods and apparatus are disclosed herein. Further not claimed examples, forms, features, aspects, benefits, and advantages of the present application shall become apparent from the description and figures provided herewith. The present invention provides an inspection and repair system according to independent claim 1 and an inspection and repair method according to independent claim 14. Preferred embodiments are set out in the dependent claims 2 to 13 and 15 to 16.

BRIEF DESCRIPTION OF THE FIGURES

[0006]

Fig. 1 shows a perspective view partially cutaway of one example of a rotor and stator of a rotating electrical machine in which a crawler can be used.

Fig. 2A illustrates a portion of an electrical machine with the stator in place and a robot crawler positioned on the teeth of the stator of the rotating electrical machine according to the invention.

Fig. 2B shows a crawler positioned on the stator teeth without the rotor in place according to the invention.

Fig. 3 shows an embodiment of a crawler.

Figs. 4A, 4B and 4C illustrate extendable modular designs for a crawler.

Fig. 5 shows an exemplary cylindrical space inspected by the crawler.

Fig. 6 shows an example of a status map in the form of a 2D array of a space shown below as inspected by the crawler.

Fig. 7 shows a flowchart illustrating a method for inspection status mapping according to the invention.

Fig. 8 shows a flowchart illustrating the method for using the inspection map to set the schedule for inspecting a space by the crawler according to the invention.

Fig. 9 shows one example of an inspection route in dashed line to be taken by a crawler.

Fig. 10 shows an exemplary video camera mounted on a crawler.

Fig. 11 shows an accelerometer-based tilt sensor mounted on one of the modules of a crawler which is not part of the invention.

Fig. 12 shows gyroscopes mounted on a crawler to provide the orientation sensed as visual feedback and/or to provide haptic feedback to the operator which are not part of the invention.

Fig. 13 shows a flowchart illustrating the method for using haptic feedback to assist with orientation of the crawler and for alerting to the operator about inspection related events according to the invention.

Fig. 14 shows exemplary inspection events that can trigger haptic feedback.

Figs. 15A and 15B show exemplary defects that may be inspected on a stator and a rotor respectively.

Fig. 16 shows an exemplary control module with associated equipment for operation of a crawler during inspection of a rotating electrical machine.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

[0007] A crawler or robot device one embodiment of which is described below is used in operations such as visual inspection, other inspections with various sensors, wedge tapping, stator repair and maintenance such as cleaning inside the air gap between the stator and the rotor of rotating electrical machinery. The machinery can include motors, generators and other rotating machines such as gearless mill drives that have an air gap suitable for crawler movement.

[0008] According to the invention, the crawler inspection can find defects on the stator and the rotor of the rotating electrical machine. One example of a stator defect is shown in Fig. 15A. This defect was a core fault caused by loose debris moving through the air gap and lodging in the radial core vents of the rotating electrical machine. One example of a rotor defect is shown in Fig. 15B. This defect was caused by cracking of a top tooth in a two pole, 60 Hz, hydrogen cooled generator.

[0009] Referring now to Fig. 1, there is shown a perspective view of one example of a rotor 16 and a stator 14 of a rotating electrical machine 10 partially cutaway in which a crawler or robot device 12 may be used for inspection in a confined space. A not claimed exemplary embodiment of the crawler 12 is shown in Fig. 3 and is described below. The rotating machine 10 can be a typical motor/generator with stator 14, rotor 16 and air gap 18. In some configurations, the crawler 12 may crawl on the teeth 14a shown in Fig. 2A of stator 14.

[0010] Fig. 2A illustrates a robot crawler 12 crawling on the teeth 14a of stator 14 with the rotor 16 in place. The teeth 14a are typically laminated steel or another ferromagnetic material. As is well known, the teeth 14a can be of different configurations of slot dimensions and shapes. Fig. 2B shows the crawler 12 crawling on the stator teeth 14a without the rotor 16 in place. For ease of illustration the copper coils in machine 10 are not shown in Figs. 2A and 2B.

[0011] Fig. 3 shows an example for a modular crawler 12. The crawler 12 can include a tethered function main module 20 and a combination of inner and outer track-drive modules 22a and 22b on each longitudinal side of module 20. A tether 20c allows the crawler 12 to communicate with a base station (not shown) that is outside of electrical

[0012] machine 10. Crawler 12 can also perform its functions without the tether 20c, i.e. through radio frequency, Wi-Fi or other wireless communication/control methods. As shown in Fig. 3, each of the drive modules 22a and 22b has a belt drive 22c. While not shown in Fig. 3 each track-drive module 22a and 22b can include a gear motor for each of the associated belt drives 22c.

[0013] Module 20 can include a visual inspection function provided by on board cameras 20a and 20b. One of the modules can also include a camera (not shown in Fig. 3) on the side facing the rotor 16 when the crawler 12 is positioned in the electrical machine 10.

[0014] Referring back to Figs. 2A and 2B, the crawler 12 is operable for crawling across and engaging with the stator teeth 14a by magnetic attachment means. One or more magnets (not shown) can be positioned on each of the drive modules 22a and 22b so as to provide sufficient force to keep the crawler attached to the machine. The crawler 12 is operable when the rotor 16 is installed in machine 10 and also when the rotor 16 is removed from machine 10.

[0015] However, in some embodiments, only the stator teeth 14a, which the belt track 22c of each of drive modules 22a and 22b ride on, are made of ferric material, the tracks 22c have to be aligned, or at least substantially aligned, with the stator teeth 14a when attached via magnet force. In other embodiments, other attachment means may be employed such as for example a plurality of suction cups adapted to extend from one or more belts 22c. Since the teeth dimension and the width ratio between the tooth 14a and wedge 14b shown in cross section in Fig. 2A vary across different machines, the tracks 22c can be adjusted to match the tooth configuration for a specific machine. As is known by the skilled artisan, wedges 14b hold the copper coils in machine 10 and the crawler 12 may include means for tapping or otherwise inspecting the wedges 14b during maintenance operations.

[0016] Figs. 4A, 4B and 4C illustrate an extendable modular design for crawler 12. As shown in Fig. 4A, crawler 12 can have one tethered function module 20 and one drive module 22 that can either be 22a or 22b or the combination thereof on each side of module 20. Thus Fig. 4A shows in schematic form the embodiment for the crawler 12 shown in Fig. 3.

[0017] As shown in Fig. 4B, crawler 12 can have a tethered function module 20 having a drive module 22 connected to each side of module 20, and a function module 24 connected to a distal side of one of the drive modules 22. An additional drive module 22 can be connected to the left side of module 24.

[0018] As shown in Fig. 4C, the modular crawler 12 can have multiple functional modules 24 and multiple drive modules 22. There can be no limit to the number of modules 22 and 24. However, a predetermined number of modules 22 and 24 are used to achieve the desired functions for a given application.

[0019] As shown in Figs. 4B, the tether 20c of function module 20 does not have to be in the center of the crawler 12 as shown in Figs. 3 and 4A. The squares shapes labeled "C" on the function modules 20 and 24 in Figs. 4A-4C each represent a camera. In some embodiments one of the function modules can include a wedge tapper "T" or other type of sensor "S". In other embodiments a repair module "R" (see Fig. 4C) may be included to repair the machine. By way of example and not limitation the repair module may include grinding tools, cutting tools, welding tools, epoxy or other adhesive applying tools, and/or debris removal tools, etc.

[0020] As can be appreciated the drive modules 22 shown in block form in Figs. 4A, 4B or 4C can be only one of modules 22a or 22b attached to each longitudinal side of tethered module 20 or non-tethered module 24. The linking between each of the modules 22 and 24 and the associated drive modules 22a or 22b can be accomplished by use of hinged spacers 15 one example of which is shown in Fig. 3 with either fixed or adjustable linkages.

[0021] In one form, the crawler 12 can perform one or more tasks such as visual inspection, measurement and repair. The crawler 12 may map the entire inspection coverage area and create a corresponding status or location status indicators in a manner that allows the inspection location and corresponding inspection data to be graphically visualized in real time or via recorded memory. As can be appreciated, localization and mapping of the air gap 18 is difficult due to its very small height (in one non-limiting example 10 mm) and long length in one non-limiting example (2 to 5 meters). In some embodiments removing the rotor to reduce challenges of small gap inspection is undesirable due to cost, time and risk of damaging the equipment.

[0022] One aspect of the present invention includes means for spatial data mapping of the inspection space. An exemplary form includes a 2D-array mapping chart 60 and is depicted in Fig. 6. This mapping data can be used for manual or auto navigation routing and planning. A micro-machined accelerometer-based tilt sensor mounted on each side of crawler tracks can be used to detect location and estimate the size of a surface irregularity.

[0023] Air gap inspection may be conducted on a regular or on an as needed basis. In one form a sensor for inspection can include a video camera mounted on the crawler 12. In the example, cameras 20a and 20b shown in Fig. 3 may be used to transmit live images to a monitor and/or a memory recording device. In operation the one or more cameras may transmit a real-time live image to the operator so that he/she can maneuver the crawler 12 and also visually inspect the structure for defects or foreign object debris.

[0024] In one aspect, it can be desirable to inspect machine structure adjacent to the air gap in a systematic manner. Systematic inspection can include inspecting portions of or inspecting the entire coverage area and corresponding status results may be mapped in such a way that the inspection location and corresponding inspection data is graphically displayed. Such a mapping task requires identification of inspection locations (or addresses) and acquisition of inspection data/results. The inspection location can be in the form of a predefined grid pattern. The grid pattern can define an array (for example [121, 23]) because the entire air gap area can be discretized by "teeth". The inspection data can include images files, surface condition (e.g. height in case of a bump, depth in case of a recessed dimple), pass/fail index, etc.

[0025] As shown in Fig. 5, an exemplary inspection space can be defined by way of example and without limitation as a cylindrical shell 50 between the rotor and the stator of the rotating machine. The position of the inspection vehicle, that is, crawler 12 shown in schematic form in Fig. 5 can for example and without limitation be defined as angular position θ, axial position z, and heading angle ϕ relative to a fixed or known location "L".

[0026] Identifying inspection location invokes techniques for solution of the localization problem typical to mobile robots. SLAM (Simultaneous Localization and Mapping) is one example of a method to build up a map within an unknown environment or to update a map within a known environment while at the same time keeping track of the current location of mobile robot(s) (by using odometers, ultrasonic sensors and/or laser scanners, etc.). For a crawler 12, it can be impractical in some applications to have bulky sensor hardware such as 1D-(single beam) or 2D-(sweeping) laser rangefinders, 3D Flash LIDAR cameras, 2D/3D sonar sensors and one or more 2D cameras, as an integral part of the system due to the size limitations.

[0027] A micro-machined accelerometer can be designed to sensitively respond to the earth's gravitational field in static application or acceleration when subjected to motion in dynamic application, or both. An accelerometer, mounted on the crawler 12, can serve as a tilt sensor for detecting current angular position for portions of the crawler 12.

[0028] In one aspect, the axial position Z (Fig. 5) can be determined by an odometry system enabled by encoders integrated in the gear motors included in the track-drive modules 22a and 22b. In one exemplary form, four encoders each of which may be integrated into track-drive module motors to continuously measure the gear motor rotation. The signal content from the four encoders can be translated into the travel distance and direction of the vehicle. Also, in some examples, one or more accelerometers can be used for calculating axial position of the vehicle 12. In some examples, the raw noisy acceleration signal transmitted directly from the sensor may be conditioned and/or filtered to eliminate/compensate for the noise (both mechanical and electrical) and inherent sensor drift. The odometry system in combination with one or more accelerometers may be utilized to keep track of the position of the vehicle 12. Other techniques for obtaining position from accelerometer data may also be used as one skilled in the art would understand.

[0029] The position information of the vehicle in the inspection area can also include the "heading" (denoted by ϕ in Fig. 5) of the vehicle 12. A gyroscope can be mounted on the vehicle 12 in such a way that it detects the vehicle's angular rotational speed (denoted by ω in Fig. 5) about the vertical axis (denoted by z_v in Fig. 5) of the local coordinate frame of the vehicle. This angular speed of the vehicle 12 is the rate of the change of the vehicle's heading angle, and therefore gives information of where the vehicle 12 is currently heading when integrated with respect to time.

[0030] An IMU (Inertial Measurement Unit) can be used with the crawler 12 in some embodiments. An IMU may include 1 or more accelerometers, gyroscopes and/or magnetometers. The IMU may include built-in signal conditioning circuits and software that measures and transmits the position, velocity, orientation, and tilt angle of the crawler 12 continuously or at discrete time intervals.

[0031] With the location information of the vehicle 12 and corresponding inspection data, an inspection map 60 sometimes also referred to herein as a status map can be generated as shown in Fig. 6, in an exemplary 2D array format. The location of the teeth 14a and thus the locational map for the teeth 14a is predefined by the specification for the machine 10. The sensors on the inspection vehicle 12 are operable for sensing and transmitting the vehicle data to a computer memory and/or a monitor for the operator to analyze. The operator may view in real time or at a subsequent time data associated with a particular position on a tooth (i.e. i=23, j=356). To that end there can be a "translator" from the sensor data to the location of that tooth on the map. Thus the data shown in the map location for that tooth is a visualization of the recorded status data for that tooth from a camera and any other status determining instrumentation mounted on the inspection vehicle 12.

[0032] Referring now to Fig. 7, there is shown a flowchart 70 for the above described inspection status mapping method by the various sensors on the vehicle 12 according to the invention. At 70a the operator moves the inspection vehicle 12 to the location in the air gap 18 to be inspected either through computer automation or through manual control. At 70b it is determined from visual guidance from the camera and/or other sensing means that the vehicle 12 has arrived at the desired location for inspection. The vehicle 12 can include one or more motion, orientation and/or location sensors. The raw data from the one or more sensors at 70c can be processed to estimate the location of the vehicle. By way of example, the vehicle may be determined to be at the [i,j]th tooth.

[0033] At 70d the vehicle 12 sends the location data to the map builder or mapping system. As shown in the flowchart the vehicle 12 has one or more inspection sensors and the data from those sensors are sent by the vehicle to the map builder. At 70e, the map builder uses the location data and the inspection data to build the status map with status indicators in the predetermined format at 70f. There is shown in this figure for the inspection status mapping flowchart a graphical display of the status map 60 (note status map 60 is also shown in Fig. 6).

[0034] One of the tasks required for motor/generator gap inspection is inspection planning and scheduling. The inspection map 60 can provide the operator with inspection history, logged data and a reference useful for future inspection plans. The scheduling criteria obtained from the inspection map 60 may include, by way of example, and not limitation: inspection completed location and data; uninspected (or uncovered) location; inspection failed location and information regarding required action; and/or a re-inspection location.

[0035] From the information above, the next inspection round can be planned in detail and the vehicle 12 can be configured for the inspection trip by mounting desired sensors and/or repair apparatus thereon. Once an inspection route and task is defined, the vehicle 12 can be operated manually, semi-autonomously or autonomously depending on how the vehicle control system is designed.

[0036] Referring now to Fig. 8, there is shown a flowchart 80 illustrating the method according to the invention for using the inspection map 60 to set the schedule for inspecting the air gap 18. At 80a there is shown the previously described inspection status map 60 and graphical display that is seen when the vehicle 12 inspects the air gap 18. Information about the status of the inspection can be displayed as desired. For example information regarding which locations were inspected as well as data obtained for those locations may be generated. Additional information may include: any locations not inspected or uncovered locations; any inspection failures for an identified location; information noting required action; and/or whether a re-inspection is required for a particular location. This information can be sent to an inspection scheduler which at 80b sets the vehicle configuration, the inspection route and the inspection task details. An exemplary inspection route 90 is shown as a dashed line in Fig. 9. The scheduler information is transmitted to the vehicle 12 and at 80c the vehicle may move using auto navigation to the inspection location. In other forms the vehicle may be moved through manual navigation or combinations of manual and auto navigation. At 80d the vehicle reports its arrival at the desired location and at 80e the inspection status is updated.

[0037] Surface irregularities can be caused by structural flaws in problem components such as delamination, a heat or stressed induced warpage, fatigue cracking, or the like as well as by foreign object or debris finding its way into the gap or path. In some aspects a video camera 100 mounted on crawler 12 as shown in Fig. 10 may not detect and/or identify all of the surface irregularities. To enhance defect detection an accelerometer based tilt sensor 110 mounted on module 22 or 24 as shown in Fig. 11 can be used. The tilt sensor 110 may be operable to detect a surface defect and estimate its size and/or shape in conjunction with the visual display. The ideal (no irregularity) surface of the air gap 18 can be defined by design criteria of the component being inspected. Any change whether abrupt or gradual in sensor readings relative to the reference values indicates the existence of defects or structural flaw on the surface. The accelerometer based tilt sensor 110 mounted on the crawler vehicle 12 as shown in Fig. 11 can provide information such as a relative magnitude of the defect or foreign object as well as a direction and intensity of the collision. The defect involved in the collision may be a part of motor structure or undesirable foreign objects located inside the air gap 18.

[0038] It should be appreciated that including one or more micro-machined motion sensors and mapping capabilities as described herein on the inspection crawler 12 along with visual inspection can provide the crawler operator with an augmented sensing capability to track what has been inspected, to plan what to inspect next, and to integrate surface defect information in the map. This integration of micro sensing technology and mapping software can provide inspection and planning information for motor and generator maintenance, without removing the rotor.

[0039] In some aspects during manual operation it can be difficult for an air gap crawler operator to maintain the correct orientation of a crawler 12 because the crawler 12 cannot be viewed directly due to the air gap's small size. Also, it is sometimes desirable to allow the operator to reorient the crawler 12, at least to a small degree, in order to allow the operator to change the orientation and/or position of the sensors or other devices on the crawler. In these instances, it may not be desirable to mechanically force the crawler 12 into one orientation, i.e. by use of mechanical guides to lock the crawler into the same orientation as a stator slot.

[0040] According to the invention, a haptic feedback can be used to help the crawler operator guide the crawler 12 without mechanically limiting the movement of the crawler 12. Gyroscopes 120 on the crawler 12 as shown in Fig. 12 can provide the orientation of the crawler 12. Knowledge of the stator design can be combined with the gyroscope's readings to calculate the deviation of the crawler 12 from the desired orientation, which is typically the nominal orientation of the stator slot. Haptic feedback can be provided to the operator through a joystick 122 such as by way of example and not limitation the Thrustmaster force feedback enabled joystick available from Guillemot Corporation S.A. to inform the operator of the deviation. The haptic feedback may help the operator to adjust the crawler 12 to a correct orientation at an early stage so that the operator may not have to make greater corrections in orientation at a later time as is shown in Fig. 12 to change the course of the crawler 12. Thresholds and various scaling functions can be used to provide more or less feedback depending on how much the operator is expected to deviate from the nominal orientation. Thresholds and scaling functions can also be tailored to operators' levels of experience and/or preferences. In some forms, haptic feedback can be used to help guide the crawler operation when in manual mode. The operator may be able to keep his/her eyes on the monitor while at the same time being able to completely focus on the inspection task at hand.

[0041] In some aspects it can be difficult for an air gap crawler operator to detect small changes in the orientation of the crawler 12 that occur when the crawler drives over an irregular surface. For example if the crawler 12 is composed of many modules linked together by various joints or spacers as shown in Fig. 11, it is possible that a module has changed orientation relative to a desired orientation. In some forms there may be no visual output to the operator and in other forms visual output may be inadequate to help the operator control the crawler 12. Therefore, it may be helpful to alert the operator to changes in the crawler state due to surface irregularities or other causes. Haptic feedback, such as vibration in the crawler joystick 122, can be used to alert the operator to the fact that the crawler 12 has driven over a bumpy surface or part of the crawler 12 has bumped into an obstacle, or that the crawler configuration or orientation has changed beyond a specified threshold. As described above, a surface defect can be detected and the size can be estimated by an accelerometer-base tilt sensor 110, but may not signal to the operator that a crawler module has changed its orientation.

[0042] Referring now to Fig. 13, a flowchart 130 includes the method according to the invention showing how haptic feedback may help the operator maintain proper orientation of the inspection crawler 12 and also how haptic feedback alerts the user to crawler related events such as rumble and vibrations. At 130a the desired location of the inspection crawler 12 can be set using the previously described inspection scheduler. The desired heading orientation is then set at 130b. The output of various sensors is used at 130c to obtain the current location of the inspection crawler 12 and the current heading orientation of the inspection crawler 12 at 130d.

[0043] The inspection crawler 12 is moved to a goal or desired location at 130e. The moving inspection crawler 12 at 130f sends haptic feedback alerts such as those described above to the operator during movement of the crawler 12. At 130g the difference between the desired and actual heading orientation is computed and at 130h the reaction force is computed as the difference computed at 130g multiplied by a software adjustable gain/scale factor. The reaction factor can be set at an appropriate level to achieve a fast response to the deviation. The computed reaction force is sent to the operator's haptic feedback device 122 and the operator feels the reaction force at 130i. The operator then at 130j uses the haptic feedback device 122 to exert a corrective force to the moving inspection crawler 12.

[0044] Air gap inspection crawlers 12 may carry sensors and devices to inspect and/or perform maintenance operations in the air gap. It is sometimes difficult for an air gap crawler operator to monitor the state of all such devices when performing an inspection. To aid the operator, some inspection events can trigger haptic feedback as shown in Fig. 14, such as a vibration through the joystick 122 or other crawler controller.

[0045] In some forms, haptic feedback can be the primary feedback means. In other forms, haptic feedback may supplement other feedback means. For example, visual feedback may be limited because the operator is looking at the crawler 12 or one of many display devices when an event occurs. In other cases audio feedback is limited because the environment can be noisy. Therefore, haptic feedback can be used instead of or as shown in Fig. 14 in addition to these other types of feedback.

[0046] In some forms the haptic feedback system can be designed such that different events result in different haptic feedback output. Some non-limiting examples include: a collision may cause the joystick 122 to move backward; slipping of the crawler (e.g. detected by two encoders in two different track modules disagreeing on the distance traveled) may cause a series of vibrations (short - short - short - delay - repeat); a loss of communication with an inspection sensor module (e.g. a wedge tapper) may cause a series of vibrations (short - long - short - long); and/or a detection of a problem by an inspection sensor module [e.g. an Electromagnetic Core Imperfection Detector (EL CID sensor)] may cause a series of vibrations (long - long - delay - repeat). Other events triggering haptic feedback could include without limitation an increased motor current for one of the track modules, an air gap height sensor detecting a narrowing of the air gap beyond a certain threshold.

[0047] Referring now to Fig. 16, there is shown an example of a control module 38 with associated equipment for facilitating operation and controlling crawler 12.

[0048] The associated equipment can include a control cabinet 38a that includes several monitors 38b, a tether 38c for connecting the crawler 12 and the control module 38, central processing unit (CPU), a DVR 38d or other memory recording means in cabinet 38a, a data input/output device 38e, communication lines in cabinet 38a with a keyboard and a mouse and a control unit 38f that has a joystick to provide feedback to the operator, lighting and speed control for the crawler 12.

[0049] While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiments have been shown and described and that all changes and modifications that come within the scope of the appended claims are desired to be protected. It should be understood that while the use of words such as preferable, preferably, preferred or more preferred utilized in the description above indicate that the feature so described may be more desirable, it nonetheless may not be necessary and embodiments lacking the same may be contemplated as within the scope of the invention, the scope being defined by the claims that follow.

Claims

1. An inspection and repair system comprising:

   a crawler (12) operable for traversing for inspection through an air gap (18) between a stator (14) and a rotor (16) of a rotating electrical machine (10); and for finding defects on the stator (14) and the rotor (16) of the electrical machine (10);
   one or more sensors (S, C) coupled with the crawler (12), the one or more sensors (S, C) operable for sensing information associated with the electrical machine (10);
   a transmitter (20c) for transmitting information from the one or more sensors (S, C) to at least one of a visual display (38b) and a retrievable memory storage (38d);
   the inspection and repair system further comprises a control system configured to transmit a haptic feedback to signal an occurrence of one of a plurality of predefined events based upon the information sensed by the one or more sensors (S, C),
   wherein the predefined events include sensing a defect in the electrical machine (10),
   wherein the control system is configured to generate an electronic result map (60) of an inspected space within the electrical machine (10) to define discrete regions with information about defects and/or foreign objects located therein, each of the discrete regions including a status indicator selected, based on sensed inspection data obtained by the crawler (12) as a defined criteria, from a plurality of different status indicators.

2. The inspection and repair system of claim 1, wherein the defect includes a foreign object located proximate the air gap (18).

3. The inspection and repair system of claim 1, wherein the one or more sensors (S, C) include at least one of a video camera (20a, 20b), an accelerometer based tilt sensor, and/or a proximity sensor; or

   further comprising a tether (20c) connected to the crawler (12) for transmitting electronic data to and from the crawler (12); or
   wherein the crawler (12) includes a main function module (20) and one or more drive modules (22a, 22b); or
   wherein the crawler (12) includes modular capability to add a plurality of function modules (20) and drive modules (22a, 22b).

4. The inspection and repair system of claim 1, wherein the control system includes a manual control device configured to transmit a haptic feedback.

5. The inspection and repair system of claim 4, wherein haptic feedback is transmitted by the manual control device when one of the predefined events is sensed by the crawler (12), wherein the plurality of predefined events preferably includes sensing a defect and/or sensing that a position or orientation of the crawler (12) is different from that of a desired position or orientation.

6. The inspection and repair system of claim 1, further comprising defining a new inspection schedule map based on the result map (60) created during a previous inspection.

7. The inspection and repair system of claim 1, further comprising:
   an inspection status system with information for scheduling an operation of the crawler (12) for creating an output map defined by discrete regions; wherein each of the discrete regions of the output

map includes a status indicator based on sensed inspection data obtained by the crawler (12).

8. The inspection and repair system of claim 7, wherein the status indicator includes information related to a surface defect, a foreign object, a pass/fail index and/or other user defined criteria; or

wherein the control system includes a tether line (38c) and/or wireless communication means operable with the crawler (12); or
wherein an inspection path for the crawler (12) is defined based on information from the status indicators of the output map; or
wherein the crawler (12) is controlled autonomously by the control system.

9. The inspection and repair system of claim 7, wherein movement of the crawler (12) is at least partially controlled by a manual control device.

10. The inspection and repair system of claim 9, wherein the manual control device includes a haptic feedback system.

11. The inspection and repair system of claim 10, wherein the haptic feedback system transmits haptic feedback output when the defect is identified, or wherein the haptic feedback system transmits haptic feedback output when the position or orientation of the crawler (12) is not within a predefined limit of a desired position or orientation; or
wherein the haptic feedback system includes a plurality of different signal definitions, each of the signal definitions corresponding to one of a plurality of different defect indicators and/or crawler orientation indicators.

12. The inspection and repair system of claim 11, wherein the magnitude of the haptic feedback is proportional to a size of the defect.

13. The inspection and repair system of claim 7 further comprising a repair module associated with the crawler (12) configured to perform a repair operation on the electrical machine (10); or
further comprising an inertial measurement unit operable with the crawler (12).

14. An inspection and repair method comprising:
providing an inspection and repair system according to claim 1, the steps comprising:

traversing the crawler (12) through the air gap (18) of the electrical machine (10);
sensing a surface of the electrical machine (10) during the traversing;
mapping the surface of the air gap (18) of the electrical machine (10), wherein the mapping includes defining the surface of the air gap (18) as a plurality of discrete regions with the status indicator and a schedule information associated therewith, wherein the status indicator comprises defects on the stator (14) and the rotor (16) of the electrical machine (10);
displaying the electronic result map (60) with the status indicators on a visual display (38b);
transmitting haptic feedback in response to the sensing of the defects on the stator (14) and the rotor (16) of the electrical machine (10) and/or a deviation from a desired position or orientation of the crawler (12).

15. The inspection and repair method of claim 14, further comprising: generating a new inspection schedule path for the crawler (12) in response to the mapping the surface of the air gap (18) of the electrical machine (10); or

wherein the status indicator indicates one of a machine defect, foreign object, pass/fail criteria, or other user defined criteria; or
wherein the sensing includes sensors (S, C) with video, orientation and/or proximity capability; or
wherein the sensing occurs on the stator (14) and/or the rotor (16) of the electrical machine (10); or wherein the moving includes input from a manual input device.

16. The inspection and repair method of claim 14, wherein a transmission magnitude of haptic feedback is proportional to a size of the defect and/or a magnitude of the deviatior from a desired position or orientation of the crawler (12); or
wherein the transmission of haptic feedback includes a plurality of different signals to correspond with a plurality of predefined status indicators.

Patentansprüche

1. Inspektions- und Reparatursystem, umfassend:

einen Kriecher (12), die bedienbar ist, um zur Inspektion einen Luftspalt (18) zwischen einem Stator (14) und einem Rotor (16) einer rotierenden elektrischen Maschine zu durchqueren; und um Defekte an dem Stator (14) und dem Rotor (16) der elektrischen Maschine (10) zu finden;
einen oder mehrere Sensoren (S, C), die mit dem Kriecher (12) gekoppelt sind, wobei der eine oder die mehreren Sensoren (S, C) bedienbar sind, um Informationen abzutasten, die mit der elektrischen Maschine (10) verbunden sind;
einen Sender (20c) zum Übertragen von Informationen von dem einen oder den mehreren

Sensoren (S, C) an mindestens eine von einer visuellen Anzeige (38b) und einer abrufbaren Speichervorrichtung (38d);

wobei das Inspektions- und Reparatursystem ferner ein Steuersystem umfasst, das konfiguriert ist, um eine haptische Rückmeldung zu übertragen, um das Vorkommen eines von einer Vielzahl von vordefinierten Ereignissen basierend auf den Informationen, die von dem einen oder den mehreren Sensoren (S, C) abgetastet werden, zu signalisieren,

wobei die vordefinierten Ereignisse das Abtasten eines Defekts in der elektrischen Maschine (10) umfassen,

wobei das Steuersystem konfiguriert ist, um eine elektronische Ergebnisdarstellung (60) eines inspizierten Raums innerhalb der elektrischen Maschine (10) zu generieren, um diskrete Regionen mit Informationen über darin befindliche Defekte und/oder Fremdkörper zu definieren, wobei jede der diskreten Regionen einen Statusindikator umfasst, der basierend auf abgetasteten Inspektionsdaten, die durch den Kriecher (12) erzielt werden, als ein definiertes Kriterium aus einer Vielzahl von verschiedenen Statusindikatoren ausgewählt wird.

2. Inspektions- und Reparatursystem nach Anspruch 1, wobei der Defekt einen Fremdkörper umfasst, der sich in der Nähe des Luftspalts (18) befindet.

3. Inspektions- und Reparatursystem nach Anspruch 1, wobei der eine oder die mehreren Sensoren (S, C) mindestens eines von einer Videokamera (20a, 20b), einem Neigungssensor auf Beschleunigungsmesserbasis und/oder einem Näherungssensor umfasst bzw. umfassen; oder

ferner umfassend ein Halteseil (20c), das mit dem Kriecher (12) verbunden ist, um elektronische Daten an den und von dem Kriecher (12) zu übertragen; oder

wobei der Kriecher (12) ein Hauptfunktionsmodul (20) und ein oder mehrere Antriebsmodule (22a, 22b) umfasst; oder

wobei der Kriecher (12) eine modulare Kapazität umfasst, um eine Vielzahl von Funktionsmodulen (20) und Antriebsmodulen (22a, 22b) hinzuzufügen.

4. Inspektions- und Reparatursystem nach Anspruch 1, wobei das Steuersystem eine manuelle Steuervorrichtung umfasst, die konfiguriert ist, um eine haptische Rückmeldung zu übertragen.

5. Inspektions- und Reparatursystem nach Anspruch 4, wobei die haptische Rückmeldung durch die manuelle Steuervorrichtung übertragen wird, wenn eines der vordefinierten Ereignisse durch den Kriecher (12) abgetastet wird, wobei die Vielzahl von vordefinierten Ereignissen bevorzugt das Abtasten eines Defekts und/oder das Abtasten, dass eine Position oder Ausrichtung des Kriechers (12) anders als eine gewünschte Position oder Ausrichtung ist.

6. Inspektions- und Reparatursystem nach Anspruch 1, ferner umfassend das Definieren einer neuen Inspektionsplandarstellung basierend auf der Ergebnisdarstellung (60), die während einer vorherigen Inspektion erstellt wurde.

7. Inspektions- und Reparatursystem nach Anspruch 1, ferner umfassend:

ein Inspektionsstatussystem mit Informationen zum Planen eines Betriebs des Kriechers (12) zum Erstellen einer Ausgabedarstellung, die durch diskrete Regionen definiert ist;

wobei jede der diskreten Regionen der Ausgabedarstellung einen Statusindikator umfasst, der auf abgetasteten Inspektionsdaten basiert, die durch den Kriecher (12) erzielt werden.

8. Inspektions- und Reparatursystem nach Anspruch 7, wobei der Statusindikator Informationen bezüglich eines Oberflächendefekts, eines Fremdkörpers, eines Pass/Fail-Index und/oder anderer benutzerdefinierter Kriterien umfasst; oder

wobei das Steuersystem eine Halteleinenleitung (38c) und/oder drahtlose Kommunikationsmittel, die mit dem Kriecher (12) bedienbar sind, umfasst; oder

wobei ein Inspektionsweg für den Kriecher (12) basierend auf Informationen von den Statusindikatoren der Ausgabedarstellung definiert ist; oder

wobei der Kriecher (12) durch das Steuersystem autonom gesteuert wird.

9. Inspektions- und Reparatursystem nach Anspruch 7, wobei die Bewegung des Kriechers (12) mindestens teilweise durch eine manuelle Steuervorrichtung gesteuert wird.

10. Inspektions- und Reparatursystem nach Anspruch 9, wobei die manuelle Steuervorrichtung ein haptisches Rückmeldungssystem umfasst.

11. Inspektions- und Reparatursystem nach Anspruch 10, wobei das haptische Rückmeldungssystem eine haptische Rückmeldungsausgabe überträgt, wenn der Defekt identifiziert wird, oder wobei das haptische Rückmeldungssystem eine haptische Rückmeldungsausgabe überträgt, wenn die Position oder Ausrichtung des Kriechers (12) nicht innerhalb einer

vordefinierten Grenze einer gewünschten Position oder Ausrichtung liegt; oder
wobei das haptische Rückmeldungssystem eine Vielzahl von verschiedenen Signaldefinitionen umfasst, wobei jede der Signaldefinitionen einem von einer Vielzahl von verschiedenen Defektindikatoren und/oder Kriecherausrichtungsindikatoren entspricht.

12. Inspektions- und Reparatursystem nach Anspruch 11, wobei die Größenordnung der haptischen Rückmeldung zu einem Ausmaß des Defekts proportional ist.

13. Inspektions- und Reparatursystem nach Anspruch 7, ferner umfassend ein Reparaturmodul, das dem Kriecher (12) zugeordnet ist und konfiguriert ist, um einen Reparaturvorgang an der elektrischen Maschine (10) vorzunehmen; oder
ferner umfassend eine Trägheitsmesseinheit, die mit dem Kriecher (12) bedienbar ist.

14. Inspektions- und Reparaturverfahren, umfassend: Bereitstellen eines Inspektions- und Reparatursystems nach Anspruch 1, wobei die Schritte umfassen:

Durchqueren durch den Kriecher (12) des Luftspalts (18) der elektrischen Maschine (10);
Abtasten einer Oberfläche der elektrischen Maschine (10) während des Durchquerens;
Darstellen der Oberfläche des Luftspalts (18) der elektrischen Maschine (10), wobei das Darstellen umfasst
Definieren der Oberfläche des Luftspalts (18) als eine Vielzahl von diskreten Regionen mit dem Statusindikator und einer dazugehörigen Planinformation, wobei der Statusindikator Defekte an dem Stator (14) und dem Rotor (16) der elektrischen Maschine (10) umfasst;
Anzeigen der elektronischen Ergebnisdarstellung (60) mit den Statusindikatoren an einer visuellen Anzeige (38b);
Übertragen einer haptischen Rückmeldung als Reaktion auf das Abtasten der Defekte an dem Stator (14) und dem Rotor (16) der elektrischen Maschine (10) und/oder eine Abweichung von einer gewünschten Position oder Ausrichtung des Kriechers (12) .

15. Inspektions- und Reparaturverfahren nach Anspruch 14, ferner umfassend:

Generieren eines neuen Inspektionsplanwegs für den Kriecher (12) als Reaktion auf das Darstellen der Oberfläche des Luftspalts (18) der elektrischen Maschine (10); oder
wobei der Statusindikator eines von einem Maschinendefekt, einem Fremdkörper, einem Pass/Fail-Kriterium oder anderen benutzerdefinierten Kriterien angibt; oder
wobei das Abtasten Sensoren (S, C) mit Video-, Ausrichtungs- und/oder Näherungskapazität umfasst; oder
wobei das Abtasten an dem Stator (14) und/oder dem Rotor (16) der elektrischen Maschine (10) erfolgt; oder
wobei das Bewegen die Eingabe von einer manuellen Eingabevorrichtung umfasst.

16. Inspektions- und Reparaturverfahren nach Anspruch 14, wobei eine Übertragungsgrößenordnung der haptischen Rückmeldung zu einem Ausmaß des Defekts und/oder einer Größenordnung der Abweichung von einer gewünschten Position oder Ausrichtung des Kriechers (12) proportional ist; oder
wobei die Übertragung einer haptischen Rückmeldung eine Vielzahl von verschiedenen Signalen umfasst, um einer Vielzahl von vordefinierten Statusindikatoren zu entsprechen.

Revendications

1. Système d'inspection et de réparation comprenant :

un engin à chenilles (12) actionnable pour traverser, à des fins d'inspection, un entrefer (18) entre un stator (14) et un rotor (16) d'une machine électrique tournante (10) ; et pour trouver des défauts sur le stator (14) et le rotor (16) de la machine électrique (10) ;
un ou plusieurs capteurs (S, C) associés à l'engin à chenilles (12), le ou les capteurs (S, C) étant actionnables pour détecter des informations associées à la machine électrique (10) ;
un émetteur (20c) pour transmettre des informations provenant du ou des capteurs (S, C) à au moins l'un parmi un dispositif d'affichage visuel (38b) et un stockage à mémoire récupérable (38d) ; et
le système d'inspection et de réparation comprend en outre un système de commande configuré pour transmettre un retour haptique pour signaler une occurrence d'un parmi une pluralité d'événements prédéfinis sur la base des informations détectées par le ou les capteurs (S, C), les événements prédéfinis comprenant la détection d'un défaut dans la machine électrique (10), le système de commande étant configuré pour générer une carte de résultat électronique (60) d'un espace inspecté à l'intérieur de la machine électrique (10) pour définir des régions discrètes avec des informations sur des défauts et/ou des objets étrangers situés à l'intérieur de celles-ci, chacune des régions discrètes comprenant un indicateur d'état sélectionné, sur la base de don-

nées d'inspection détectées obtenues par l'engin à chenilles (12) comme critères définis, parmi une pluralité d'indicateurs d'état différents.

2. Système d'inspection et de réparation selon la revendication 1, dans lequel le défaut comprend un objet étranger situé à proximité de l'entrefer (18).

3. Système d'inspection et de réparation selon la revendication 1, dans lequel le ou les capteurs (S, C) comprennent au moins un parmi une caméra vidéo (20a, 20b), un capteur d'inclinaison basé sur accéléromètre et/ou un capteur de proximité ; ou

comprenant en outre une attache (20c) reliée à l'engin à chenilles (12) pour transmettre des données électroniques vers et depuis l'engin à chenilles (12) ; ou
dans lequel l'engin à chenilles (12) comprend un module de fonction principal (20) et un ou plusieurs modules d'entraînement (22a, 22b) ; ou
dans lequel l'engin à chenilles (12) a une capacité modulaire pour ajouter une pluralité de modules de fonction (20) et de modules d'entraînement (22a, 22b).

4. Système d'inspection et de réparation selon la revendication 1, dans lequel le système de commande comprend un dispositif de commande manuelle configuré pour émettre un retour haptique.

5. Système d'inspection et de réparation selon la revendication 4, dans lequel un retour haptique est émis par le dispositif de commande manuelle lorsque l'un des événements prédéfinis est détecté par l'engin à chenilles (12), la pluralité d'événements prédéfinis comprenant, de préférence, la détection d'un défaut et/ou la détection du fait qu'une position ou une orientation de l'engin à chenilles (12) est différente de celle d'une position ou orientation souhaitée.

6. Système d'inspection et de réparation selon la revendication 1,
comprenant en outre la définition d'une nouvelle carte de planification d'inspection sur la base de la carte de résultat (60) créée pendant une inspection précédente.

7. Système d'inspection et de réparation selon la revendication 1, comprenant en outre :
un système d'état d'inspection avec des informations pour planifier une opération de l'engin à chenilles (12) pour créer une carte de sortie définie par des régions discrètes ; chacune des régions discrètes de la carte de sortie comprenant un indicateur d'état sur la base de données d'inspection détectées obtenues par l'engin à chenilles (12).

8. Système d'inspection et de réparation selon la revendication 7, dans lequel l'indicateur d'état comprend des informations relatives à un défaut de surface, un objet étranger, un indice de réussite/échec et/ou d'autres critères définis par l'utilisateur ; ou

dans lequel le système de commande comprend une ligne d'attache (38c) et/ou un moyen de communication sans fil actionnable avec l'engin à chenilles (12) ; ou
dans lequel un chemin d'inspection pour l'engin à chenilles (12) est défini sur la base d'informations provenant des indicateurs d'état de la carte de sortie ; ou
dans lequel l'engin à chenilles (12) est commandé de manière autonome par le système de commande.

9. Système d'inspection et de réparation selon la revendication 7, dans lequel un mouvement de l'engin à chenilles (12) est au moins partiellement commandé par un dispositif de commande manuelle.

10. Système d'inspection et de réparation selon la revendication 9, dans lequel le dispositif de commande manuelle comprend un système de retour haptique.

11. Système d'inspection et de réparation selon la revendication 10, dans lequel le système de retour haptique émet une sortie de retour haptique lorsque le défaut est identifié, ou dans lequel le système de retour haptique émet une sortie de retour haptique lorsque la position ou l'orientation de l'engin à chenilles (12) n'est pas dans une limite prédéfinie d'une position ou orientation souhaitée ; ou
dans lequel le système de retour haptique comprend une pluralité de définitions de signal différentes, chacune des définitions de signal correspondant à l'un d'une pluralité d'indicateurs de défaut différents et/ou d'indicateurs d'orientation d'engin à chenilles différents.

12. Système d'inspection et de réparation selon la revendication 11, dans lequel la grandeur du retour haptique est proportionnelle à une taille du défaut.

13. Système d'inspection et de réparation selon la revendication 7, comprenant en outre un module de réparation associé à l'engin à chenilles (12), configuré pour effectuer une opération de réparation sur la machine électrique (10) ; ou
comprenant en outre une unité de mesure inertielle actionnable avec l'engin à chenilles (12).

14. Procédé d'inspection et de réparation comprenant :
disposer un système d'inspection et de réparation

selon la revendication 1, les étapes comprenant :

déplacer l'engin à chenilles (12) à travers l'entrefer (18) de la machine électrique (10) ;
détecter une surface de la machine électrique (10) pendant le déplacement ;
cartographier la surface de l'entrefer (18) de la machine électrique (10), la cartographie comprenant la définition de la surface de l'entrefer (18) sous la forme d'une pluralité de régions discrètes avec l'indicateur d'état et des informations de planification associées à celles-ci, l'indicateur d'état comprenant des défauts sur le stator (14) et le rotor (16) de la machine électrique (10) ;
afficher la carte de résultat électronique (60) avec les indicateurs d'état sur un dispositif d'affichage visuel (38b) ;
émettre un retour haptique en réponse à la détection des défauts sur le stator (14) et le rotor (16) de la machine électrique (10) et/ou d'un écart par rapport à une position ou orientation souhaitée de l'engin à chenilles (12).

15. Procédé d'inspection et de réparation selon la revendication 14, comprenant en outre : générer un nouveau chemin de planification d'inspection pour l'engin à chenilles (12) en réponse à la cartographie de la surface de l'entrefer (18) de la machine électrique (10) ; ou

l'indicateur d'état indiquant l'un parmi un défaut de machine, un objet étranger, des critères de réussite/échec ou d'autres critères définis par l'utilisateur ; ou
la détection comprenant des capteurs (S, C) ayant une capacité vidéo, d'orientation et/ou de proximité ; ou
la détection se produisant sur le stator (14) et/ou le rotor (16) de la machine électrique (10) ; ou
le déplacement comprenant une entrée provenant d'un dispositif d'entrée manuelle.

16. Procédé d'inspection et de réparation selon la revendication 14, dans lequel une grandeur d'émission du retour haptique est proportionnelle à une taille du défaut et/ou à une grandeur de l'écart par rapport à une position ou orientation souhaitée de l'engin à chenilles (12) ; ou
dans lequel l'émission du retour haptique comprend une pluralité de signaux différents pour correspondre à une pluralité d'indicateurs d'état prédéfinis.

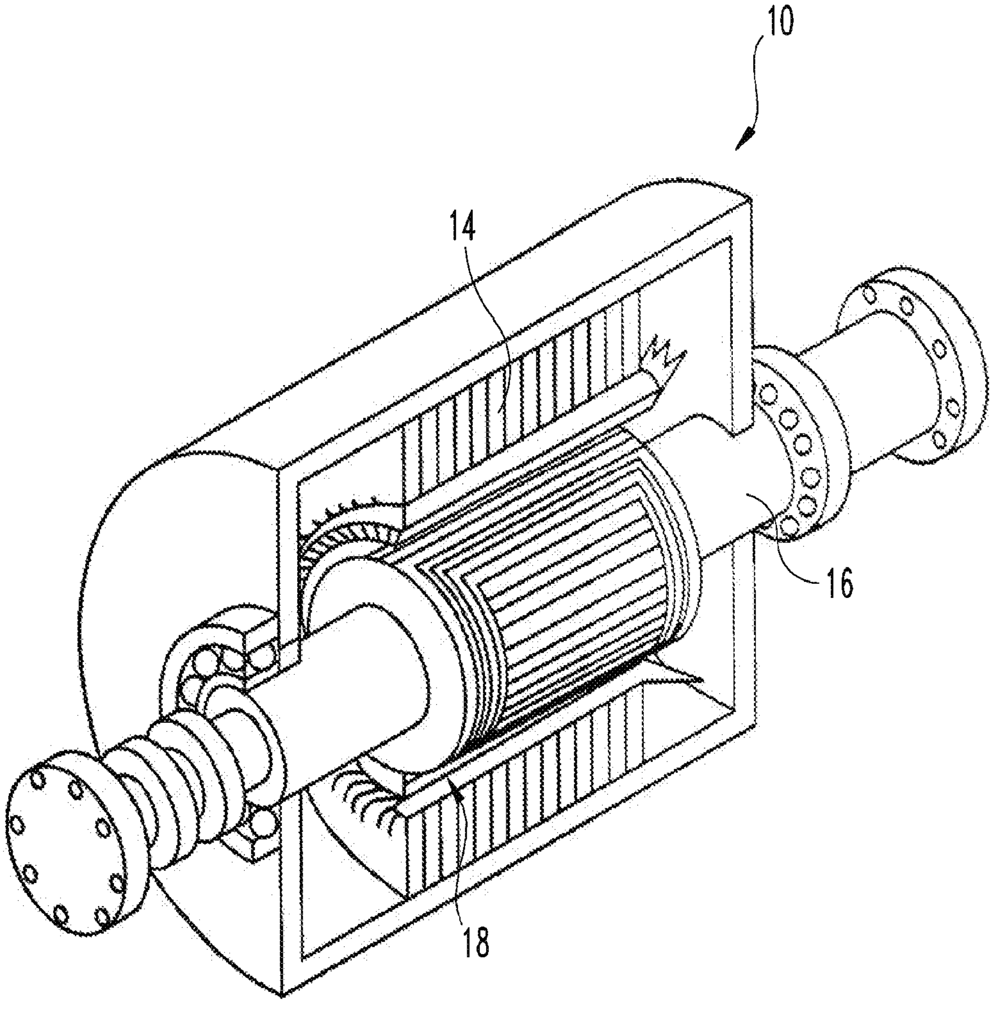


FIG. 1

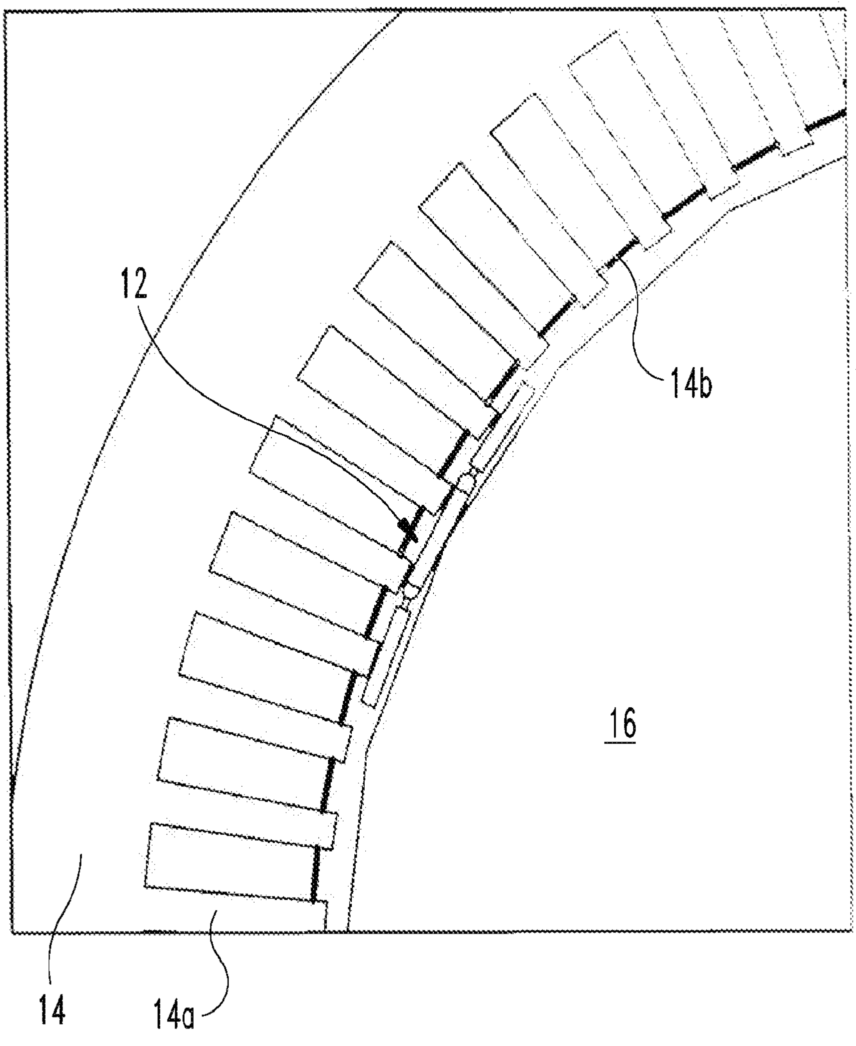


FIG. 2A

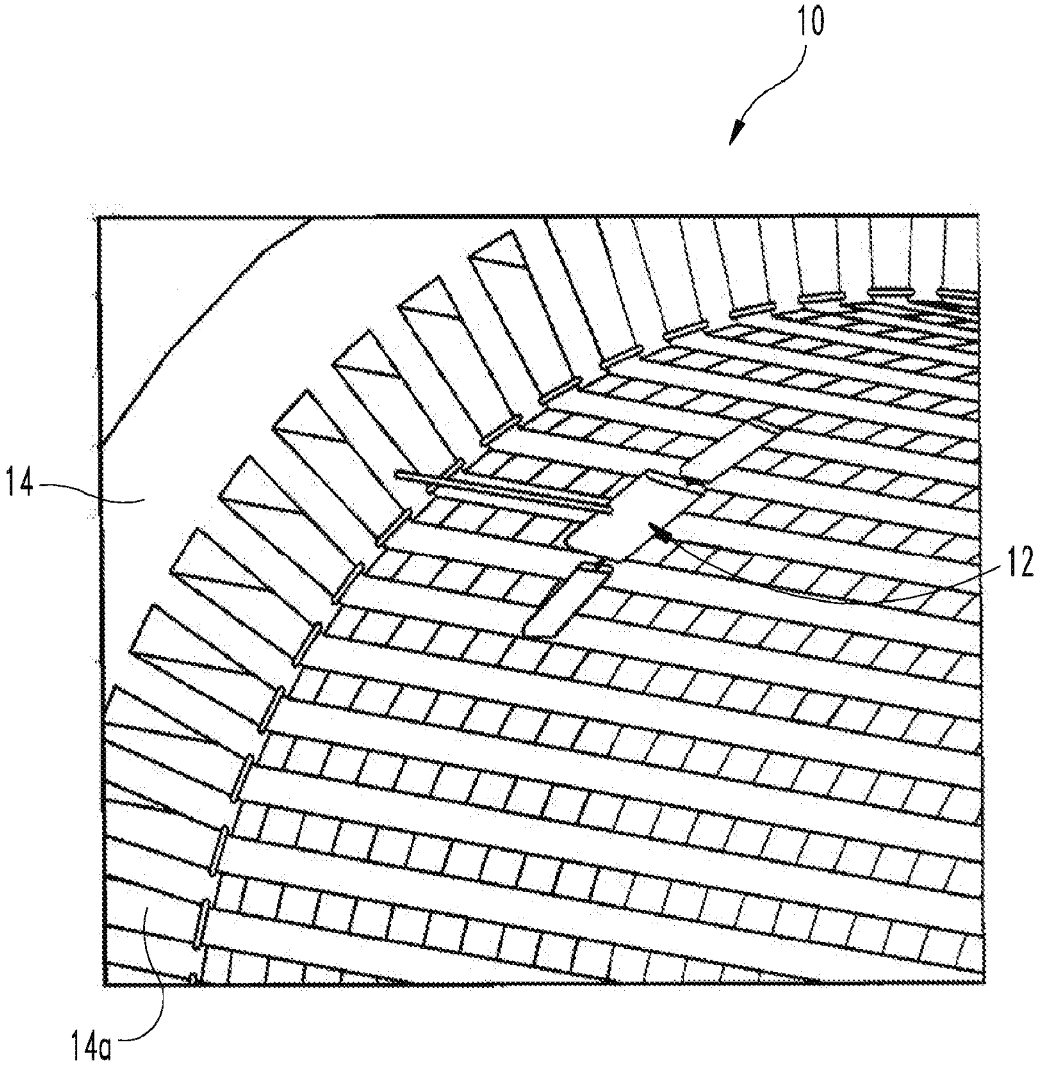


FIG. 2B

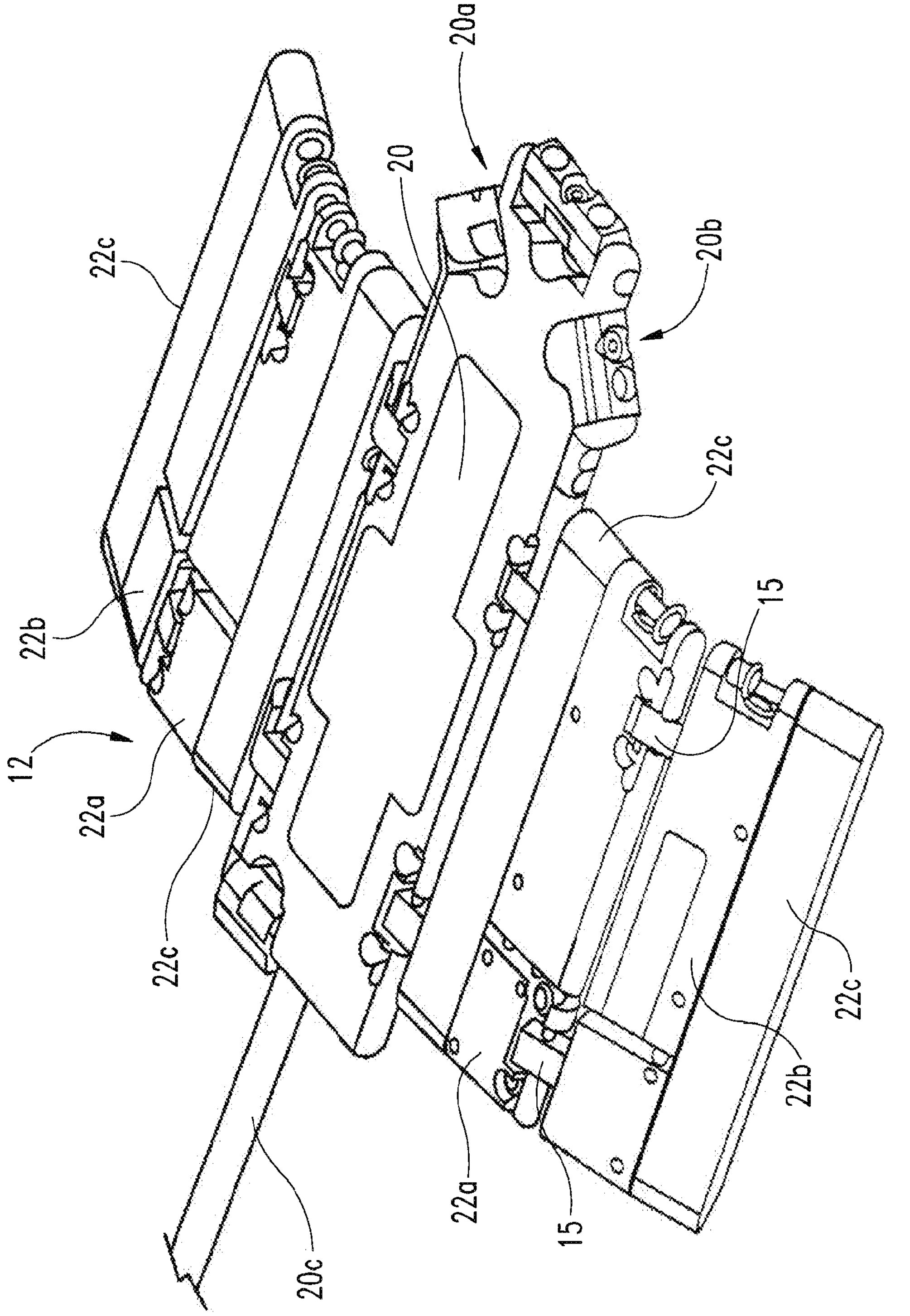


FIG. 3

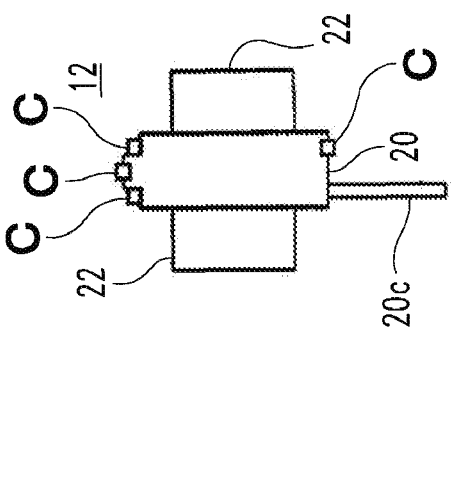


FIG. 4A

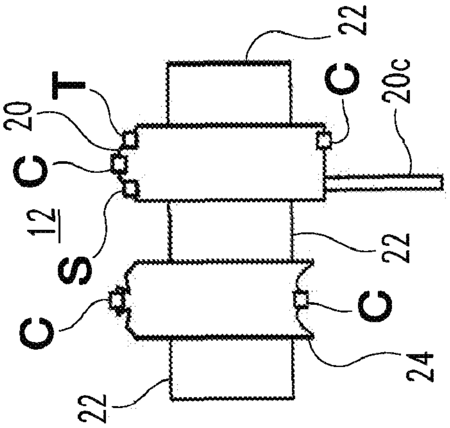


FIG. 4B

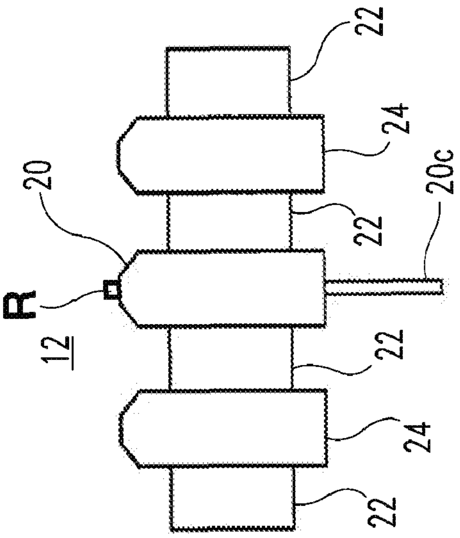


FIG. 4C

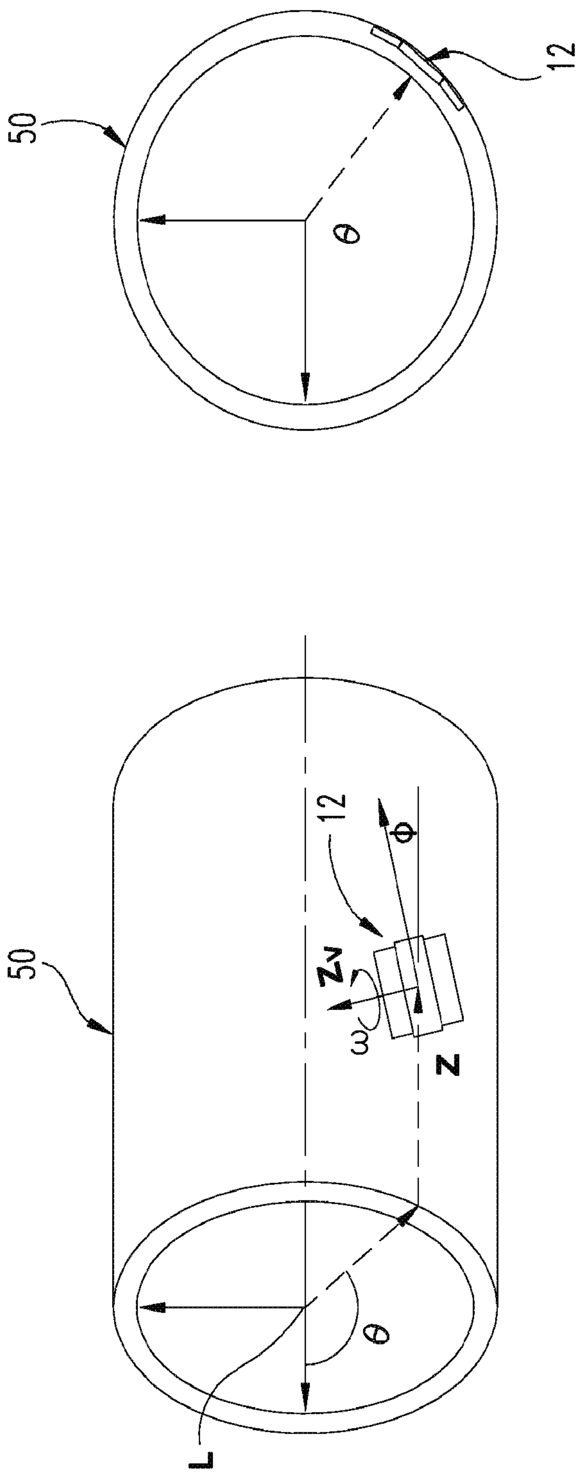


FIG. 5

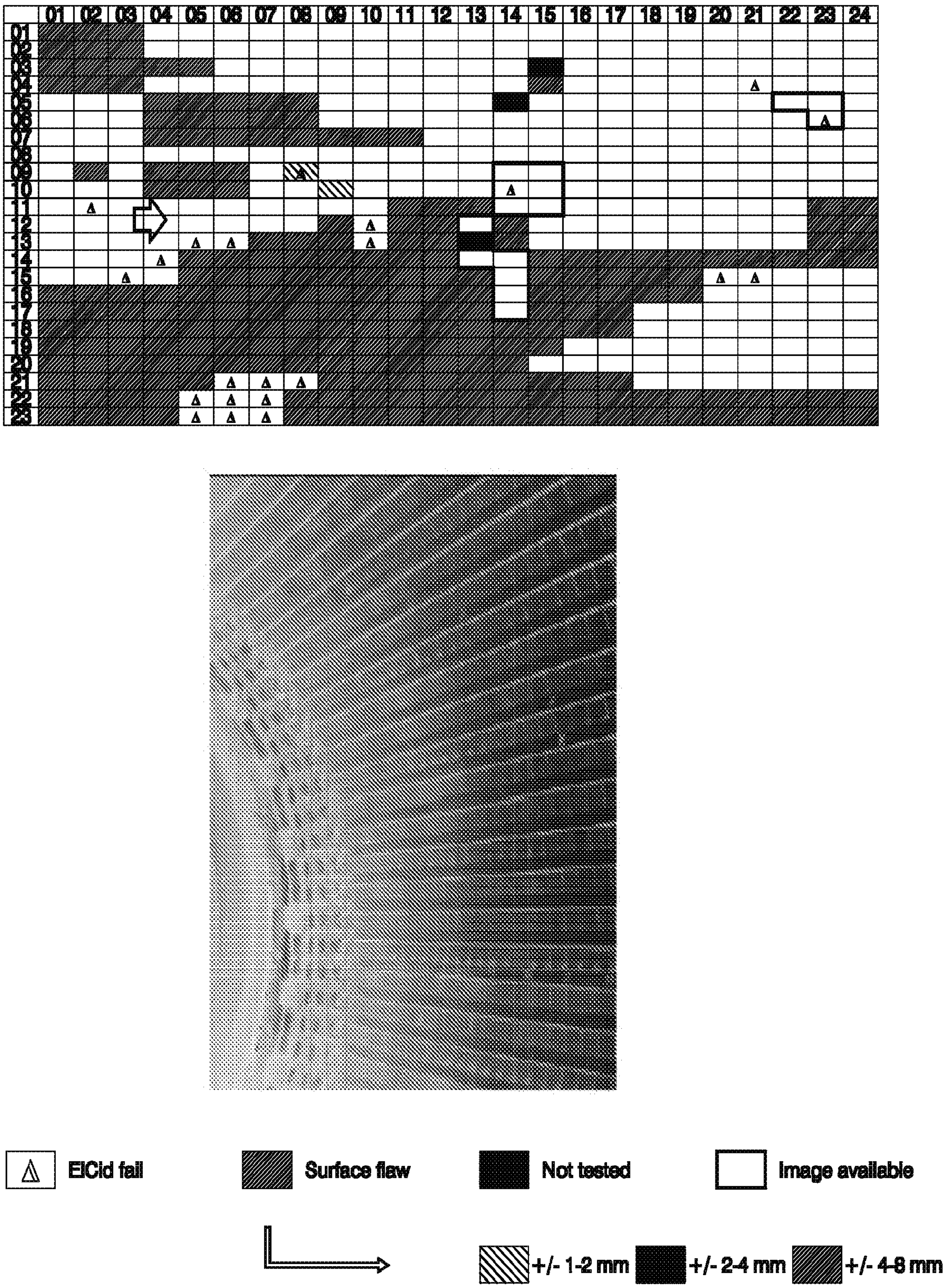

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
ElCid fail
Surface flaw
Not tested
Image available
+/- 1-2 mm
+/- 2-4 mm
+/- 4-8 mm

FIG. 6

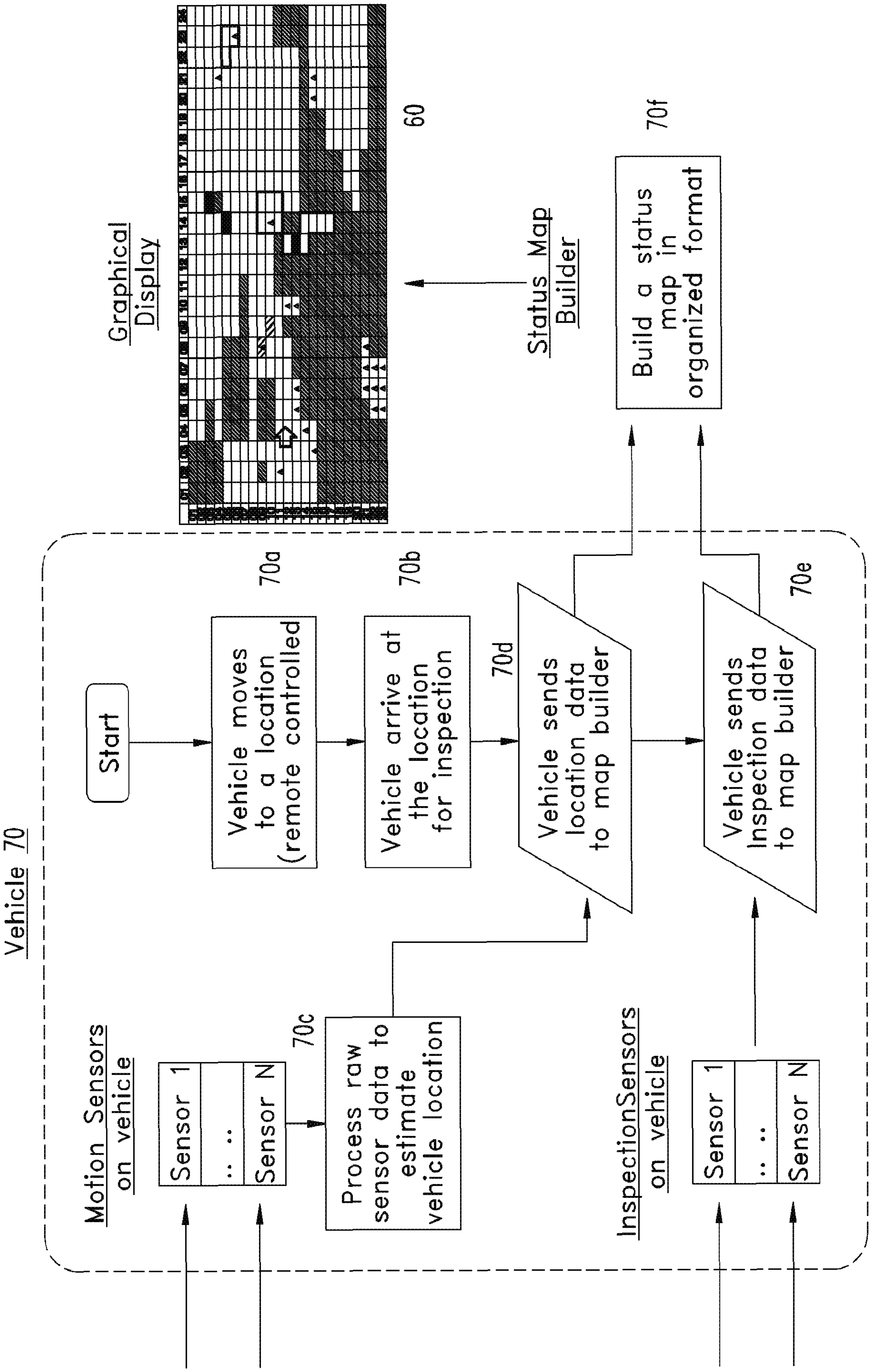

Vehicle 70
Motion Sensors on vehicle
Sensor 1
.. ..
Sensor N
Process raw sensor data to estimate vehicle location
70c
InspectionSensors on vehicle
Sensor 1
.. ..
Sensor N
Start
Vehicle moves to a location (remote controlled
70a
Vehicle arrive at the location for inspection
70b
Vehicle sends location data to map builder
70d
Vehicle sends Inspection data to map builder
70e
Graphical Display
60
Status Map Builder
Build a status map in organized format
70f

FIG. 7

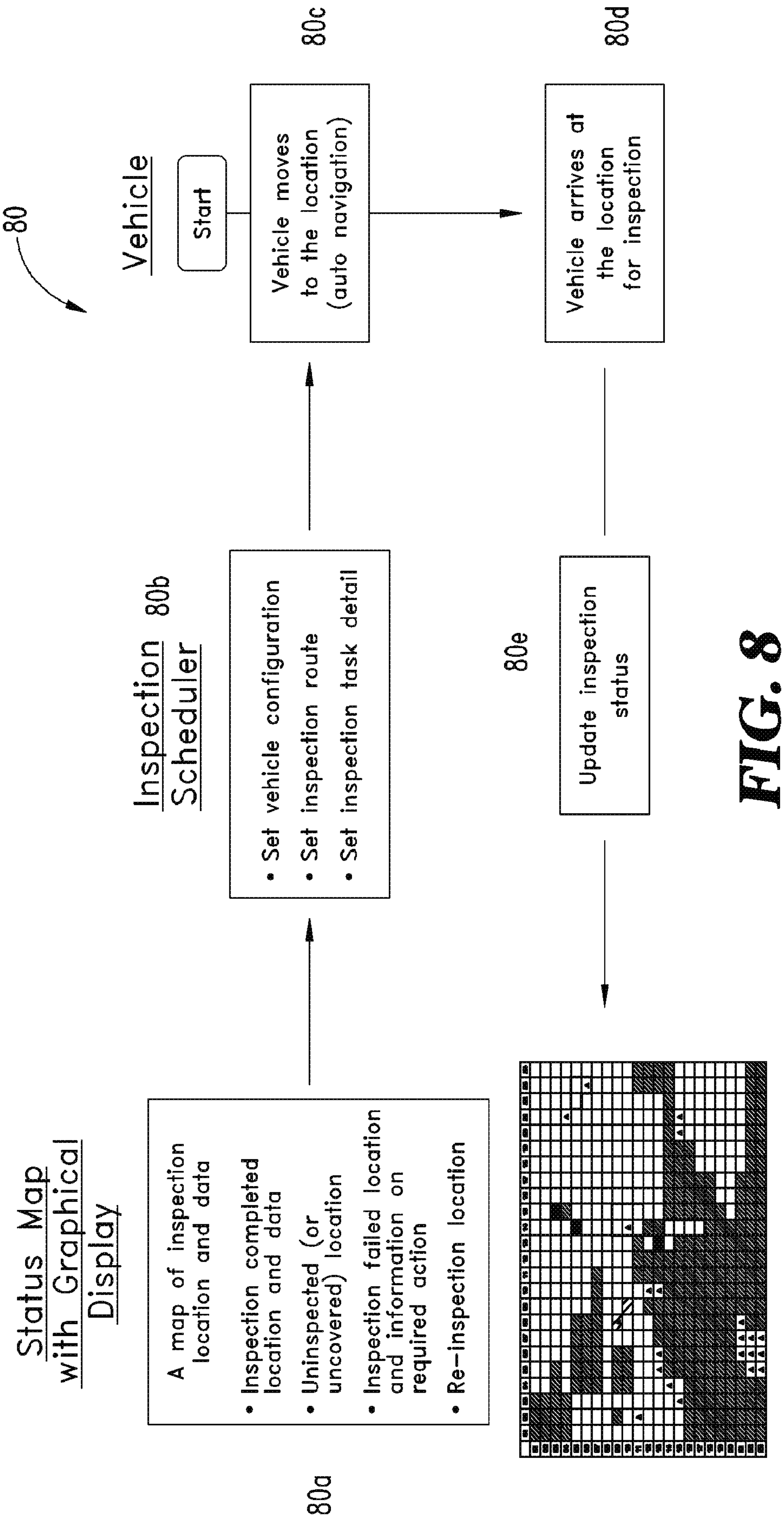

80
Status Map with Graphical Display
80a
A map of inspection location and data
• Inspection completed location and data
• Uninspected (or uncovered) location
• Inspection failed location and information on required action
• Re-inspection location
Inspection Scheduler
80b
• Set vehicle configuration
• Set inspection route
• Set inspection task detail
Vehicle
Start
80c
Vehicle moves to the location (auto navigation)
80d
Vehicle arrives at the location for inspection
80e
Update inspection status

FIG. 8

90

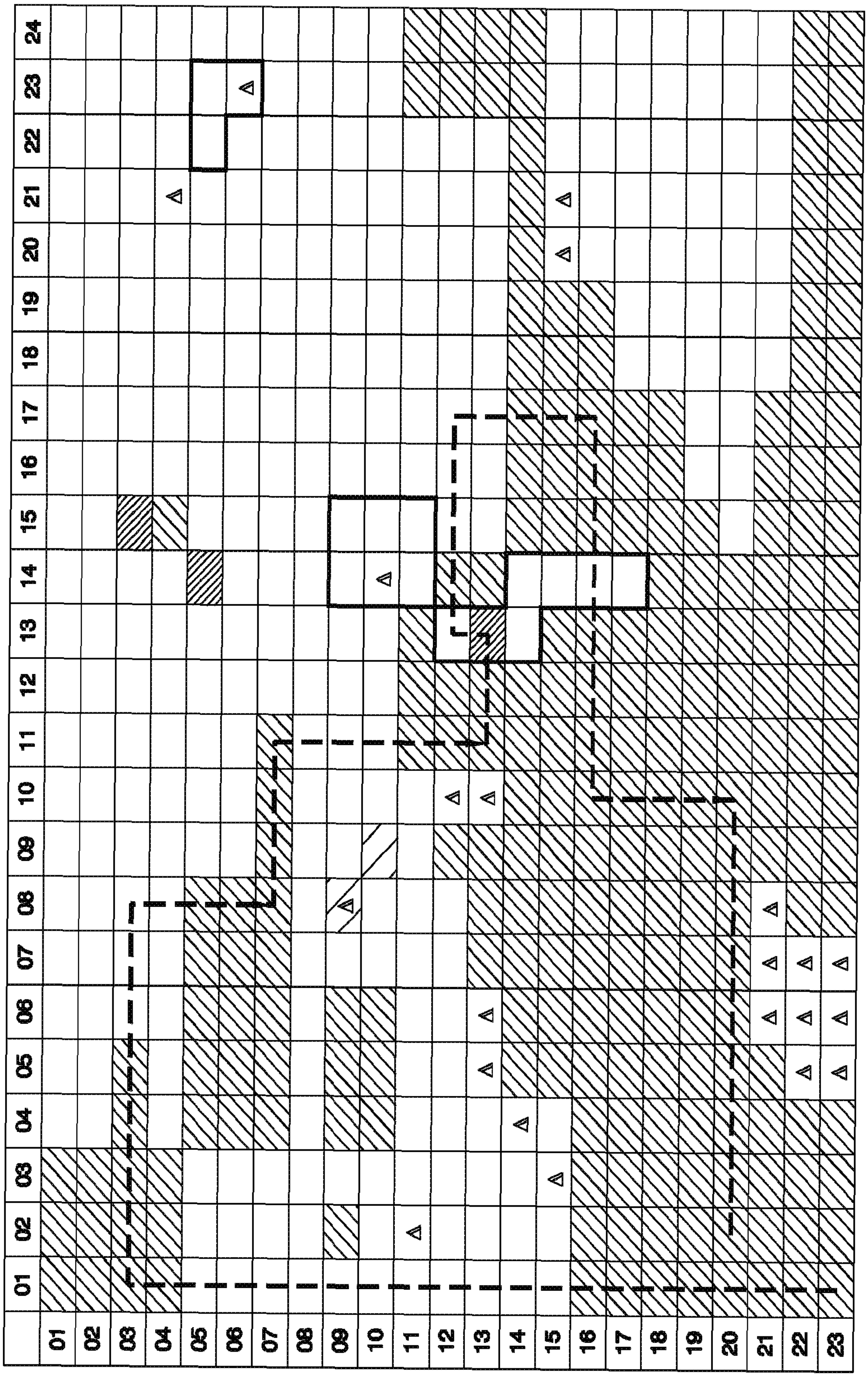
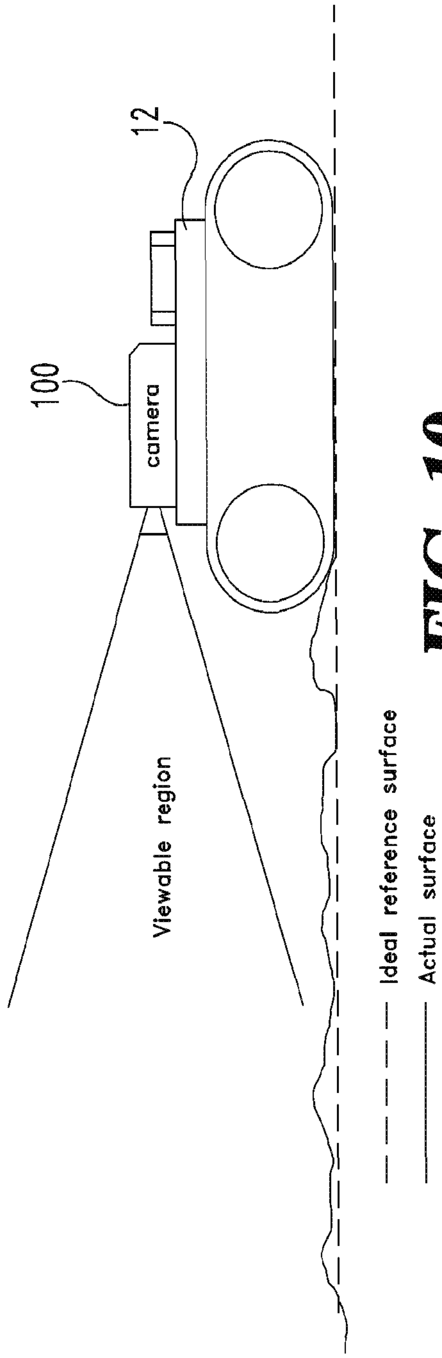
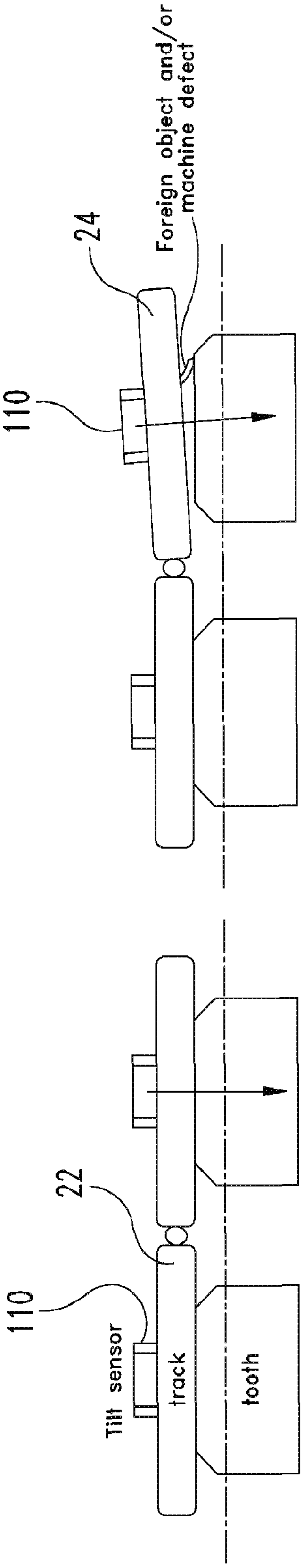

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23

FIG. 9



100
camera
12
Viewable region
Ideal reference surface
Actual surface

FIG. 10



24
Foreign object and/or machine defect
110
110
Tilt sensor
22
track
tooth

FIG. 11

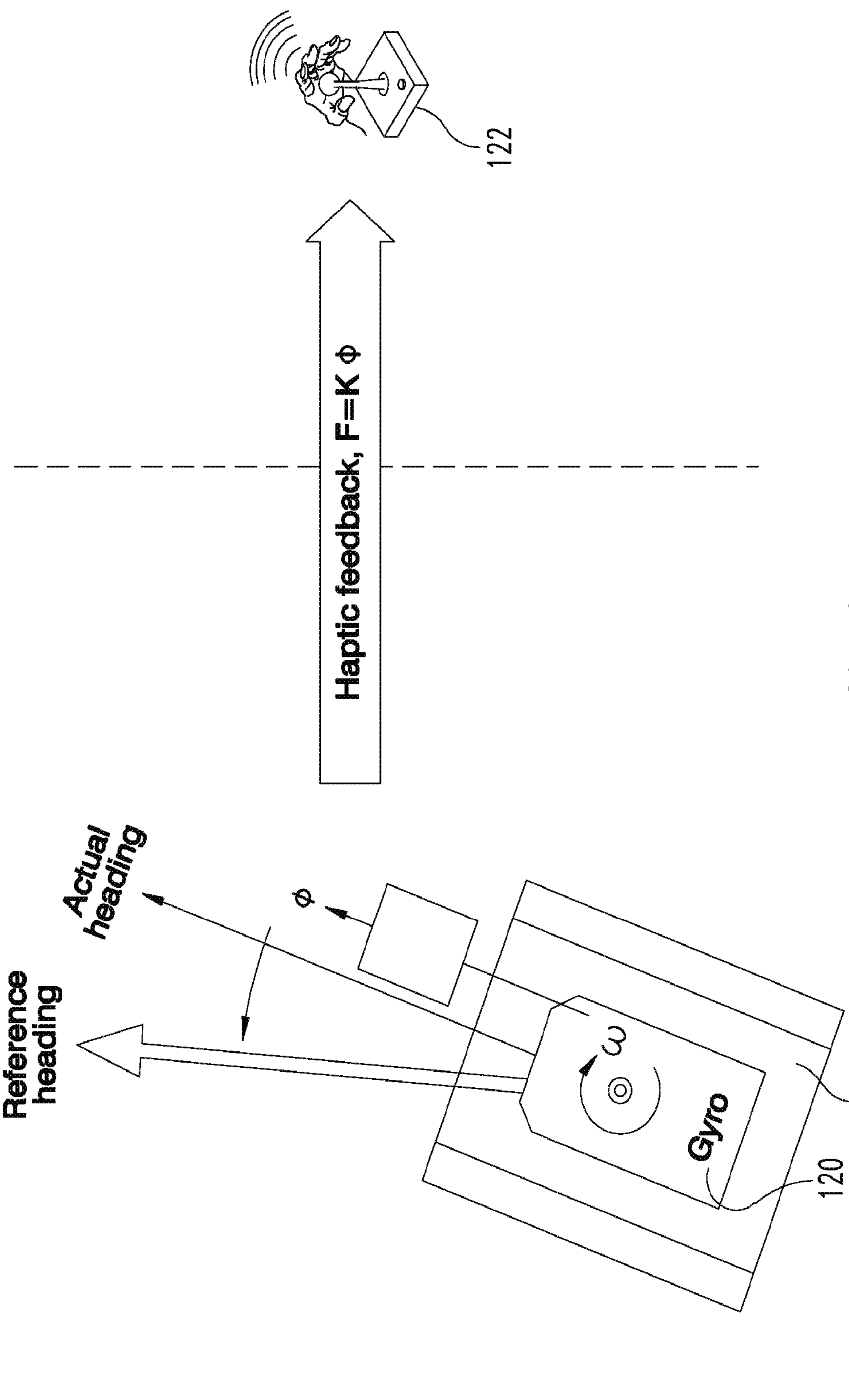

Reference heading
Actual heading
φ
ω
Gyro
120
12
Haptic feedback, F=K φ
122

FIG. 12

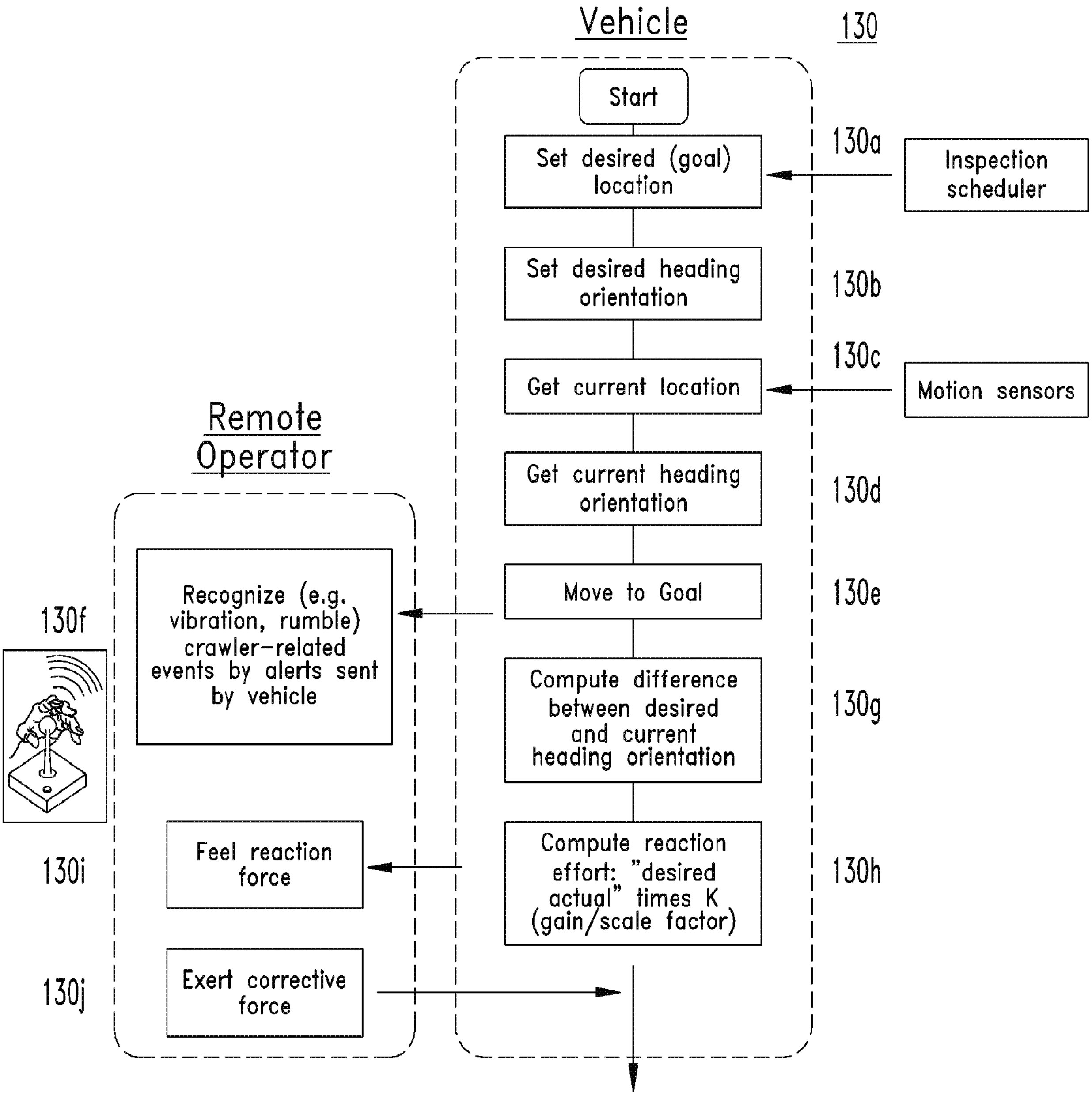

Vehicle
130
Start
Set desired (goal) location
130a
Inspection scheduler
Set desired heading orientation
130b
Get current location
130c
Motion sensors
Get current heading orientation
130d
Move to Goal
130e
Compute difference between desired and current heading orientation
130g
Compute reaction effort: "desired actual" times K (gain/scale factor)
130h
Remote Operator
130f
Recognize (e.g. vibration, rumble) crawler-related events by alerts sent by vehicle
130i
Feel reaction force
130j
Exert corrective force

FIG. 13

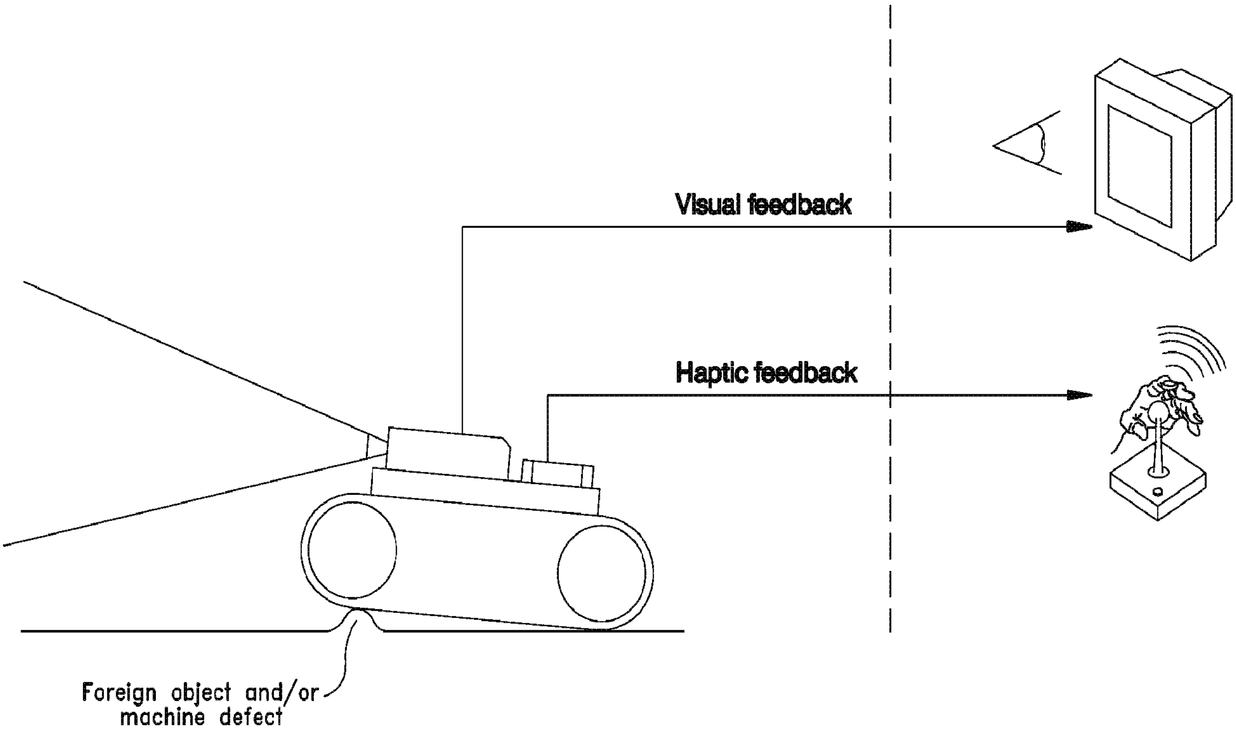

Visual feedback
Haptic feedback
Foreign object and/or
machine defect

FIG. 14

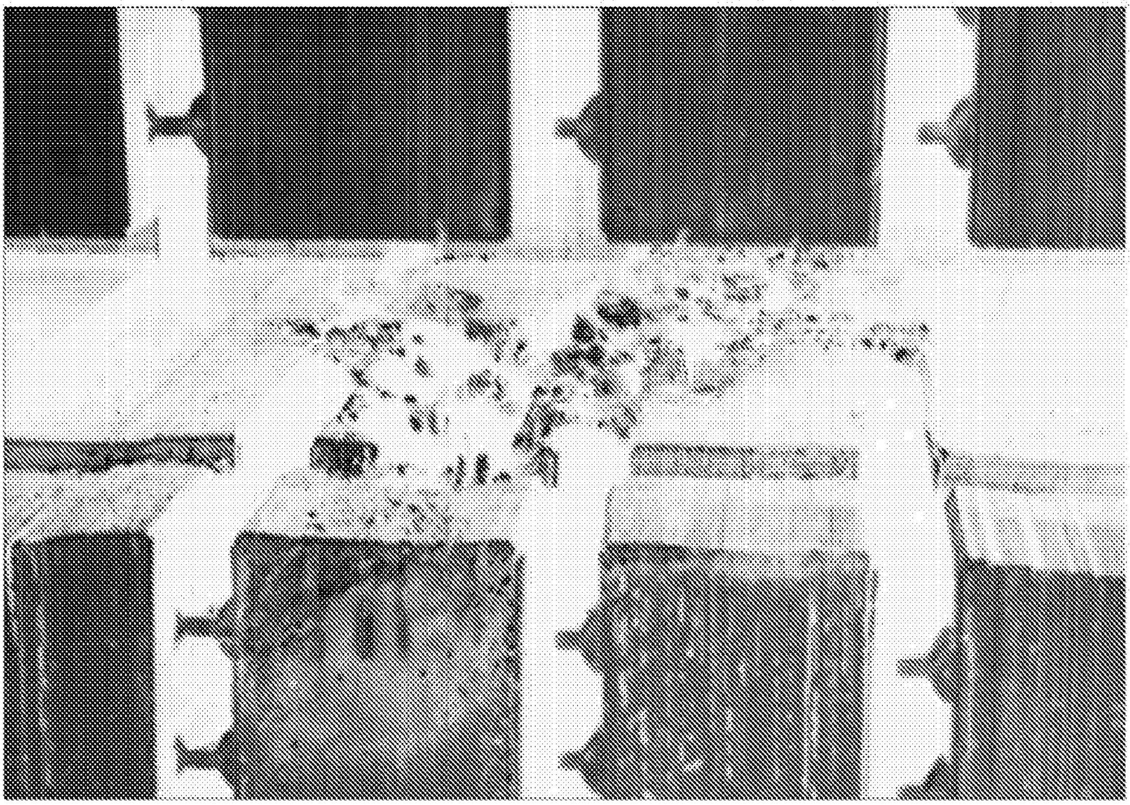


FIG. 15A

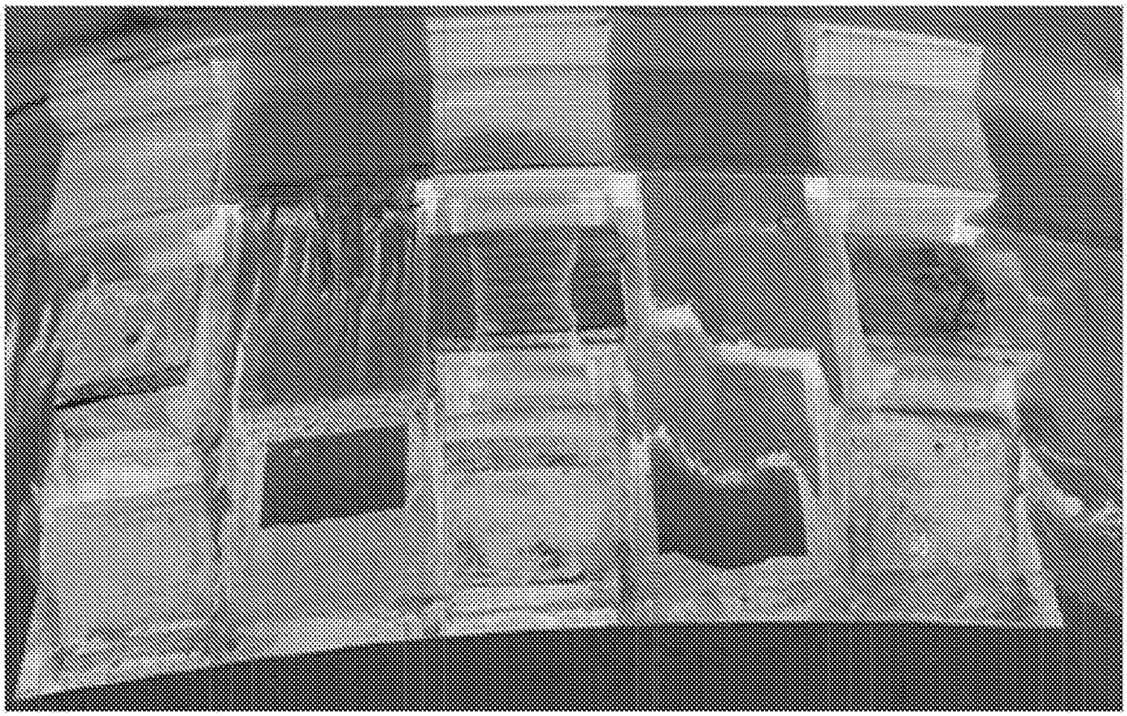


FIG. 15B

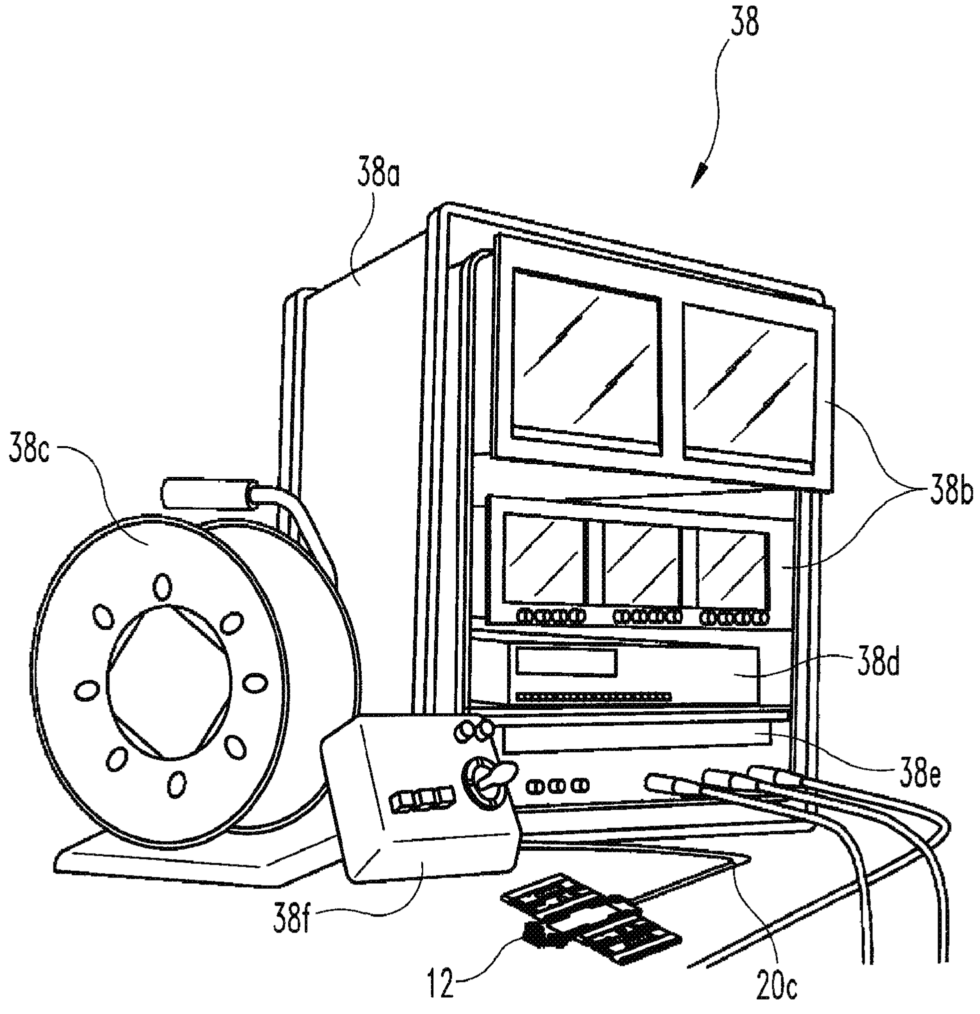


FIG. 16

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 1772949 A1 **[0003]**
- US 4889000 A **[0004]**